July 2024

WORKING PAPER SERIES

2024-EQM-06

How can agricultural production be reconciled with environmental preservation: ‘Land sparing’ versus ‘Land sharing’?

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Preliminary version

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This work benefited from a PhD grant n°MESR 2018-25 from the University of Bourgogne Franche-Comté, DGEP doctoral school, CESAER UMR1041, INRAE, Institut Agro, F-21000 Dijon, France.

Abstract

Balancing agricultural production with environmental preservation is a major challenge in the agricultural sector. We address this issue by evaluating two land management strategies: land sharing and land sparing. Using an efficiency analysis based on an activity model, we assess the potential for implementing these strategies across different farm categories, defined by land quality (yield index) and subsidy levels. Applied to farm data from the Meuse department (2006–2016), our results show that agricultural production can align with environmental preservation by either sparing 16% of farmland for the environment or reducing the use intensity of operational inputs by 13% across all farmlands. For farms with low land quality, land sparing would be more appropriate, whereas high land quality farms would benefit more from land sharing. Both land sharing and land sparing would better suit large farms with fewer subsidies; meaning that as farm size and subsidy levels increase, their contribution to these strategies diminishes. Our findings emphasize the need to consider farm characteristics in implementing agricultural land management strategies for environmental preservation.

Keywords: agricultural production, environmental preservation, land sharing, land sparing, activity model, Meuse department.

JEL classification: Q1, Q5, R14.

1. Introduction

Reconciling agricultural production with biodiversity and environmental preservation is one of the foremost concerns in the agriculture sector today. Intensive and industrialized practices that have been long implemented in agriculture to increase agricultural productivity and ensure food security have resulted in significant consequences for biodiversity and the environment (Bianchi et al., 2007; Björklund et al., 1999; Dale and Polasky, 2007; Donald et al., 2001; Krebs et al., 1999; Kremen et al., 2002; MEA, 2005; Sassen et al., 2022). The services provided by ecosystems have deteriorated over time in favor of maximizing agricultural yields (MEA, 2005). Because the sustainability of agriculture depends on the provision of ecosystem services such as pollination, nutrient recycling, pest control, carbon sequestration, water flow regulation and so forth (MEA, 2005), the interest in restoring and preserving these services is crucial. One suggested way to reduce the impact of agriculture on the environment and biodiversity is to manage agricultural intensity (see Teillard, 2012; Teillard et al., 2017, among others). Agricultural intensity is also considered to be a key factor in increasing production and a determinant of biodiversity erosion. To balance production with biodiversity conservation, Teillard (2012) and Teillard et al. (2017) analyzed not only the effectiveness of different scenarios of agricultural intensity (intensification, extensification, reallocation), but also their optimal allocation in the farming area. Their results highlight the importance of spatial planning in the allocation of agricultural intensity to manage farmland biodiversity. Regarding biodiversity, Shi et al. (2021) and Muller et al. (2017) studied the role of intensification in balancing agricultural production with the provision of other ecosystem services, such as carbon storage and soil conservation. In our work, we focused solely on the environmental aspect of agriculture. We analyze how agricultural production can be reconciled with the environment through agricultural intensity adjustment and its spatial allocation under different land management strategies.

Inspired by the ecology literature, we analyze two options to reduce the pressure of agriculture on the environment in a context where competition for various land uses is increasing: either adopt extensive agriculture that is less harmful to the environment and apply this across all farmlands or intensify the land usage on a reduced area so that some land can be entirely spared for the environment. In a study on biodiversity conservation, Green et al. (2005) described the first option, which consists of expanding wildlife-friendly farming over a large area, as *land sharing*, and the second option, which advocates for a spatial separation of agricultural production from biodiversity conservation, as *land sparing*. These two strategies were first applied to biodiversity conservation on farmlands (Dotta et al., 2016; Fischer et al., 2014; Hulme et al., 2013; Kamp et al., 2015; Kremen, 2015; Phalan et al., 2011; Teillard et al., 2017) before being extended to biodiversity preservation in urban areas (Caryl et al., 2016; Collas et al., 2017; Soga et al., 2014; Stott et al., 2015) as well as in forests (Edwards et al., 2014; Paul and Knoke, 2015; Warman and Nelson, 2016). Few studies have been dedicated to the provision of ecosystem services (Durrant and Ely, 2022; Shi et al., 2021) or to other issues such as water quality preservation in agriculture (Legras et al., 2018). Following these studies that extend land sparing and land sharing to other issues than farmland biodiversity, we applied the two strategies to the question of environmental preservation in general by choosing different agricultural practices.

Having been developed in ecology, the implementation of land sharing and land sparing has been mainly approached from an ecological perspective; the economic and social aspects have so far been little addressed. Because these two strategies do not have the same implications in terms of land allocation, their implementation requires the definition of certain choice criteria. From an ecological point of view, the choice between land sharing and land sparing is based on the relationship between production and biodiversity through the agricultural yield-species density curve (Fischer et al., 2014; Green et al., 2005; Phalan et al., 2011). In the case of a convex relationship, the land-sparing strategy, which suggests allocating land either to agricultural production or wildlife preservation, would be preferable. In the case of a concave relationship, the land-sharing strategy, which allows for both agricultural production and wildlife preservation to be allocated on the same land, would be preferable. In addition to this choice criterion based on yields and species density, other studies have underlined the importance of economic, political and social criteria (Desquilbet et al., 2017; Hagemann et al., 2020; Legras et al., 2018; Salles et al., 2017). According to these studies, the choice and implementation of the two strategies should take into account the social welfare and rational behaviour of farmers (Salles et al., 2017), the cost-effectiveness of each strategy with respect to the considered economic incentives (Legras et al., 2018), the soil quality heterogeneities and influence of public policies (Martinet and Barraquand, 2012), the effects of the market through prices and demand for agricultural goods (Desquilbet et al., 2017) and the trend of socioeconomic development in the future (Hagemann et al., 2020). In our analysis, the choice between and implementation of land sharing-land sparing are based on the efficiency measures and the characteristics of farms.

We categorized farms using two criteria to account for their characteristics: land quality, measured by the yield index, and the level of subsidies received. Our aim is to determine whether land sharing or land sparing would be more appropriate for farms based on their land quality and subsidy levels. In the literature, Martinet and Barraquand (2012) also considered soil quality heterogeneities when analyzing the choice between land sharing and land sparing for biodiversity conservation in agricultural landscapes. Their theoretical model assessed the impact of varying land quality on these two management strategies. In line with their study, our work examines both land quality and subsidy levels using an empirical model.

Since the development of the land-sharing and land-sparing strategies by Green et al. (2005), numerous studies have focused on their conceptualization and on the scope of their application using theoretical analyses and models (Fischer et al., 2014; Kremen, 2015; Martinet and Barraquand, 2012; Paul and Knoke, 2015; Phalan et al., 2011; Salles et al., 2017; Soga et al., 2014). Applications of these strategies have been carried out using density-yield functions with parametric approaches (Desquilbet et al., 2017; Dotta et al., 2016; Edwards et al., 2014; Hulme et al., 2013; Kamp et al., 2015) and optimization methods (Legras et al., 2018; Shi et al., 2021; Teillard et al., 2017). Our contribution involves applying an activity model with data envelopment analysis (DEA) to implement land sharing and land sparing for environmental preservation in agriculture, considering our two criteria.

DEA, a non-parametric method developed by Charnes et al. (1978), measures the efficiency of decision-making units across various domains, including agriculture. Despite criticisms for not accounting for risk and exogenous factors, DEA was chosen for three reasons: (1) it does not require specifying a functional form between variables, (2) it measures efficiency without input and output prices, and (3) it handles multiple inputs and outputs in a multi-objective analysis. For greater flexibility, we used directional distance functions developed by Chambers et al. (1998, 1996), allowing specific directional projections to the efficiency frontier. An input-oriented measure was chosen for land sparing and both input- and output-oriented perspectives for land sharing to measure the extent to which farmers can reduce agricultural intensity on all farmlands: first at a given level of production and, second, by considering the increase in production.

We applied our efficiency measures to arable farms located in the Meuse department in the northeast of France. We proceed in two steps: first, we computed individual efficiency measures for each land management strategy, second, we aggregated individual inefficiency scores at the scale of farm groups made from the two defined criteria to determine for which category of farms land-sharing and land-sparing strategies would be more appropriate. Our results show that farms contribute differently to the two strategies based on their compliance with one criterion or another.

The remainder of the present paper is structured as follows: The second section presents our efficiency measures. The third section presents the data used. The results are given and discussed in the fourth section, and in the last section, we conclude the paper.

2. Methodology

In efficiency measures using the DEA method, agricultural land management remains underdeveloped, with few studies mainly from China. For instance, Fei et al. (2021) used a nonradial directional distance function and propensity-score-matching to assess land efficiency amid urbanization. Kuang et al. (2020) examined how cultivated land is used to maximize desirable outputs while minimizing carbon emissions. Pascual (2005) focused on improving land efficiency in Mexico's forest-fallow cultivation to reduce ecological damage from plot burning.

In our study, we use directional distance functions (DDF) to assess the potential for implementing land-sharing and land-sparing strategies for environmental preservation. DDF are efficiency measures that project an input–output vector onto the efficiency frontier in a preassigned direction (Chambers et al., 1998, 1996). We assign a specific direction to each efficiency measure of land sharing and land sparing.

Let *K* be the total number of farms k = (1, … , *K*), also called decision-making units (DMUs), that transform a vector of *N* inputs $x_k = (x_{1k}, \dots, x_{Nk}) \epsilon R_+^N$ into a vector of *M* outputs $y_k = (y_{1k}, \dots, y_{Mk}) \epsilon R_+^M$. The vector of inputs x_k is divided into variable inputs (indexed by v) and fixed inputs (indexed by f): $x_k = (x_{vk}, x_{fk})$. In fixed inputs, land (x_{fk^L}) is distinguished from capital and labor ($x_{fk^{K,W}}$). Each farm *k* is faced with the technology of production given by $T_k = \{(x_k, y_k) \epsilon\, R_+^{n+m} \colon x_k\ can\ produce\ y_k\}$. Based on assumptions presented in Fried et al. (2008), we assume that the technology T_k satisfies these standard assumptions of the production possibility set:

1. Convexity

If $(x_k, y_k) \in T_k$ and $(x'_k, y'_k) \in T_k$,

then $(\alpha(x_k, y_k) + (1-\alpha)(x'_k, y'_k)) \in T_k$ for any $\alpha \in [0,1]$.

2. Free disposability of inputs and outputs

If $(x_k, y_k) \in T_k$ and $x'_k \geq x_k$ then $(x'_k, y_k) \in T_k$

If $(x_k, y_k) \in T_k$ and $y'_k \leq y_k$ then $(x_k, y'_k) \in T_k$

3. No output can be produced without some input.

If $y_k \geq 0$ and $y_k \neq 0$, then $(0, y_k) \notin T_k$.

4. $T_k\ (x_k)$ is bounded for $x_k \in R_+^n$

5. Inclusion of observations

Each observed DMU $(x_o, y_o) \in T_k$

For each farm k, the general formulation of the directional distance function defined on this technology T_k is given by the following:

$$\vec{d}(x_k, y_k, -g_x, g_y) = Sup\left\{\beta : \left(x_k - \beta g_x, y_k + \beta g_y\right) \epsilon\, T_k\right\} \quad (1)$$

where β is the measure of inefficiency and $g = (-g_x, g_y)$ the vector of direction in which the input–output vector (x_k, y_k) is projected onto the efficiency frontier T_k. The DDF $\vec{d}(x_k, y_k, -g_x, g_y)$ simultaneously measures the maximum expansion of outputs and contraction of inputs to reach the efficiency frontier. $\vec{d}(x_k, y_k, -g_x, g_y) = 0$ when the evaluated farm k is efficient and $\vec{d}\left(x_k, y_k, -g_x, g_y\right) > 0$ when it is inefficient.

The vector of direction $g = (-g_x, g_y)$ can be specified according to the objective pursued. In our analysis, we assigned a specific direction to each measure of land sharing and land sparing. In the land-sparing strategy, which measures the potential for agricultural land reduction at a given level of outputs, we orient our efficiency measure in the direction of the ‘input land’. In the land-sharing strategy, which aims at reducing agricultural intensity on existing farmlands, we consider the direction of ‘variable inputs’ in the first option (where outputs are considered at their current level) and direction of ‘variable inputs and outputs’ in the second option (where outputs can be expanded). This second option allows us to measure the extent to which both productive and environmental objectives can be improved on the same land. This refers to the notion of sustainable intensification, which consists of increasing food production while minimizing pressure on the environment (Alves-Pinto et al., 2017; Garnett et al., 2013; Godfray and Garnett, 2014; Martin-Guay et al., 2018; Pretty, 2018; Zuluaga et al., 2021). Leaner programming models corresponding to these strategies are presented below.

2.1. Land-sparing strategy

In this strategy, DMUs are projected onto the efficiency frontier in the direction of the input land noted x_{fL}. To allow for the aggregation of efficiency scores at the department level, we chose the same direction for all DMUs in each year T. The directional vector is then given by g = $\left(-g_x^T, g_y^T\right) = \left(-\sum_{k=1}^{K} x_{fk^L}^T, 0\right)$. For each farm k in each year, the linear programming is given by the following:

$$\vec{d}(\ x_k^T, y_k^T, -g_x^T, 0) = \max_{\beta,\lambda_k} \beta$$

Subject to:

$$\begin{array}{ll}
\sum_{k=1}^{K} \lambda_k y_{rk}^T \geq y_{ro}^T & r = (1, \dots, M) \\
\sum_{k=1}^{K} \lambda_k x_{fk^L}^T \leq x_{fo^L}^T - \beta * \sum_{k=1}^{K} x_{fk^L}^T & f^L = (1, \dots, \mathrm{n}) \\
\sum_{k=1}^{K} \lambda_k x_{fk^{K,W}}^T \leq x_{fo^{K,W}}^T & f^{K,W} = (n+1, \dots, n') \\
\sum_{k=1}^{K} \lambda_k x_{vk}^T \leq x_{vo}^T & v = (n'+1, \dots, N) \\
\sum_{k=1}^{K} \lambda_k = 1 & k = (1, \dots, K) \\
\lambda_k \geq 0, \beta \geq 0 &
\end{array} \tag{2}$$

This program seeks the maximum contraction of agricultural land that can be achieved for the DMU*o* while producing at least as much as before. β is the inefficiency score, which corresponds to the proportion of the total agricultural land each DMU can reduce to reach the efficiency frontier. λ_k is the value of the intensity variable of the DMU k calculated from the best observed DMUs that make the efficiency frontier.

2.2. Land-sharing strategy

This strategy consists of reducing agricultural intensity on existing agricultural land. In the literature, Teillard et al. (2017) measured agricultural intensity for each farm as the ratio between the sum of its different categories of input costs[1] and its utilized agricultural area (UAA). Following these authors, we measured agricultural intensity as the ratio between variable input costs and the UAA.

Two options are considered for this strategy. In the first option, aiming at reducing the use of variable inputs to a given level of output, DMUs are projected onto the efficiency frontier in the sole direction of variable inputs. The directional vector is given by g = $\left(-g_x^T, g_y^T\right) = \left(-\sum_{k=1}^{K} x_{vk}^T, 0\right)$. As in the previous strategy, the same direction is chosen for all DMUs in each period T.

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[1] These input costs include pesticides, fertilizers, feedstuff, fuel, seeds, veterinary products and irrigation water.

For each farm k, the linear programming model is given by the following:

$$\vec{d}(\ x_k^T, y_k^T, -g_x^T, 0) = \max_{\beta,\lambda_k} \beta$$

Subject to:

$$\sum_{k=1}^{K} \lambda_k y_{rk}^T \geq y_{ro}^T \qquad r = (1, \dots, M) \tag{3}$$

$$\sum_{k=1}^{K} \lambda_k x_{fk^L}^T = x_{fo^L}^T \qquad f^L = (1, \dots, \text{n})$$

$$\sum_{k=1}^{K} \lambda_k x_{fk^{K,W}}^T \leq x_{fo^{K,W}}^T \qquad f^{K,W} = (n+1, \dots, n')$$

$$\sum_{k=1}^{K} \lambda_k x_{vk}^T \leq x_{vo}^T - \beta * \sum_{k=1}^{K} x_{vk}^T \qquad v = (n'+1, \dots, N)$$

$$\sum_{k=1}^{K} \lambda_k = 1 \qquad k = (1, \dots, K)$$

$$\lambda_k \geq 0, \beta \geq 0$$

For each DMUo, this program measures the maximum contraction of variable inputs that can be achieved at a given level of output while, at most, using the current level of other inputs. As can be seen here, we replace the inequality sign with equality on the land constraint. The aim is to maintain land at the observed level to ensure that the reduction in costs is indeed accompanied by a reduction in their use intensity. λ_k is the value of the intensity variable of the DMU k calculated from the best observed DMUs.

In the second option for the land-sharing strategy, we measure to what extent the objective of production and the environmental goal of reducing agricultural intensity can be improved simultaneously on the same agricultural land. DMUs are projected onto the efficiency frontier in the direction of variable inputs and outputs. The directional vector becomes g = $\left(-g_x^T, g_y^T\right) = \left(-\sum_{k=1}^{K} x_{vk}^T, \sum_{k=1}^{K} y_{rk}^T\right)$ for all DMUs.

The linear programming for each DMU k is given by the following:

$$\vec{d}(\, x_k^T, y_k^T, -g_x^T, 0) = \max_{\beta,\lambda_k} \beta$$

Subject to:

$$\sum_{k=1}^{K} \lambda_k y_{rk}^T \geq y_{ro}^T \; + \beta * \sum_{k=1}^{K} y_{rk}^T \qquad r = (1, \dots, M) \tag{4}$$

$$\sum_{k=1}^{K} \lambda_k x_{fk^L}^T \; = \; x_{fo^L}^T \qquad f^L = (1, \dots, \mathrm{n})$$

$$\sum_{k=1}^{K} \lambda_k x_{fk^{K,W}}^T \leq x_{fo^{K,W}}^T \qquad f^{K,W} = (n+1, \dots, n')$$

$$\sum_{k=1}^{K} \lambda_k x_{vk}^T \leq x_{vo}^T - \beta * \sum_{k=1}^{K} x_{vk}^T \qquad v = (n'+1, \dots, N)$$

$$\sum_{k=1}^{K} \lambda_k = 1 \qquad k = (1, \dots, K)$$

$$\lambda_k \; \geq 0, \beta \; \geq 0$$

Here, we also consider the same direction for all DMUs. β is the inefficiency score and λ_k the value of the intensity variable for the DMU k.

3. Data

We applied our methodology to farm data from the Meuse department. These data are provided by the French National Research Institute for Agriculture, Food and Environment (INRAE) and produced by the Meuse and Meurthe-et-Moselle Centre of Accountancy and Management (CERFRANCE Adheo 109). In Meuse, agricultural land covers 55% of the territory, with field crops making up 57% of this area. The main agricultural outputs are field crops (cereals and oilseeds) at 41%, dairy at 24%, and beef production at 14%[2]. Our analysis focuses on farms specialized in field crops, where these crops generate more than two-thirds of total revenue. Livestock and grassland are included as control variables because farm-level expenses cannot be accurately divided between these productions without clear distribution information. We then selected an unbalanced sample of 1044 observations observed over the period 2006-2016. The distribution of these observations per year is given in Table 1. The highest number is observed in 2010 (133 observations), and the lowest in 2016 (59 observations). One can note that the number of farms specialized in field crops has been

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[2] https://meuse.chambre-agriculture.fr/

decreasing since the year 2011. This can be partly explained by the decrease in the number of farms in Meuse over the last ten years: -2.6% between 2010 and 2020 (Agreste-RA 2020)[3].

To keep the possible variabilities in the data that may be because of pedoclimatic or economic conditions from one year to another, each year is considered individually in the efficiency analysis. The results are presented on average over the whole period to obtain an overview of the potential for each land management strategy.

Table 1: Number of observations per year

Year	Number of observations	Share in %
2006	71	6.8%
2007	107	10.2%
2008	117	11.2%
2009	99	9.5%
2010	133	12.7%
2011	118	11.3%
2012	101	9.7%
2013	88	8.4%
2014	80	7.7%
2015	71	6.8%
2016	59	5.7%
Total	1044	100.0%

Regarding the variables of our model, we considered two outputs measured in euros: (i) crop production composed of wheat, maize, barley, peas, rapeseed, sunflower, diester, agronomic and other energy fallow and (ii) other productions, that include grasslands and animal products. These outputs are produced by fixed and variable inputs. Fixed inputs include utilized agricultural area (UAA) measured in hectares, capital measured in euros approximated by the depreciation of materials and buildings, as well as other agricultural service providers, and labor measured in annual work units (AWU) which includes family and hired labor. Variable inputs measured in euros are composed of intermediate consumption for crops (fertilizers and seeds), for livestock (feedstuffs, veterinary costs, animal husbandry costs), other intermediate consumption (fuel, water, gas, electricity) and pesticides (herbicides, insecticides, fungicides, regulators and other chemical products). Prices of these inputs and outputs are considered exogeneous in our model, i.e., farms are supposed to be price takers. Descriptive statistics of these variables are presented in Table 2 for the Meuse department.

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[3] In Agreste Grand Est - Mémento 2022

Table 2. Descriptive statistics for the 1044 observations over the period 2006-2016

	Mean	Standard deviation	Min	Max	Coefficient of variation
Outputs					
Crops production (in €)	191,083	109,042	15,558	972,265	57%
Other productions (in €)	38,293	33,449	0	193,317	87%
Inputs					
Land (in ha)	225	107	48	801	48%
Crop lands (in ha)	187	96	27	755	52%
Other lands (in ha)	39	35	0	174	90%
Labor (in AWU)	1.63	0.84	0.2	5	51%
Capital (in €)	68,983	43,220	7,092	399,321	63%
Operational costs (in €)	107,428	56,107	12,608	404059	52%
Intermediate consumptions (in €)	76,845	41,885	7,475	322920	55%
Pesticides (in €)	30,583	17,140	2,484	119894	56%

As can be seen in Table 2, on average over the full period, a farm produces 191,083 euros of crops and 38,293 euros of other production on 225 hectares of land per year. This land is mainly allocated to crops, with other productions that occupy only 39 hectares on average. Labor and capital are used at an average of 1.63 AWU and 68,983 euros, respectively. Operational costs average 107,428 euros, of which pesticides account for 30,583 euros (i.e. 28%). Crop production is mainly composed of wheat, barley, and rapeseed, which represent 86.7% of the total crop area. Considering the level of operation costs regarding the total agricultural area, the use intensity of variable inputs in Meuse is 477 euros per ha on average. For some farms, the entire activity is devoted to crop production. These farms are the minority and represent less than 1% of our sample.

As mentioned in the introduction, we categorized farms based on land quality and subsidy levels to determine which farms might benefit more from land-sharing or land-sparing strategies. We created three groups using the yield index associated to each small region (district) of Meuse. This index indicates the potential yield achievable in each district based on its pedological conditions. The index value fluctuates within a range, with a minimum of 0.9088 and a maximum of 1.1624, centering around an average value of 1.0040. Following the evolution of this index, presented in Figure 1, we defined two thresholds: one closest to the average (1.0022) and another corresponding to the first quartile (0.95). Our first group is therefore made up of farms located in districts where the yield index value is less than 0.9503, the second group is of farms with the yield index comprised between 0.9503 and 1.0022, and the third group of farms with the yield index value greater than 1.0022. Some characteristics of these groups per year are given in Table 3.

Figure 1. Evolution of the yield index

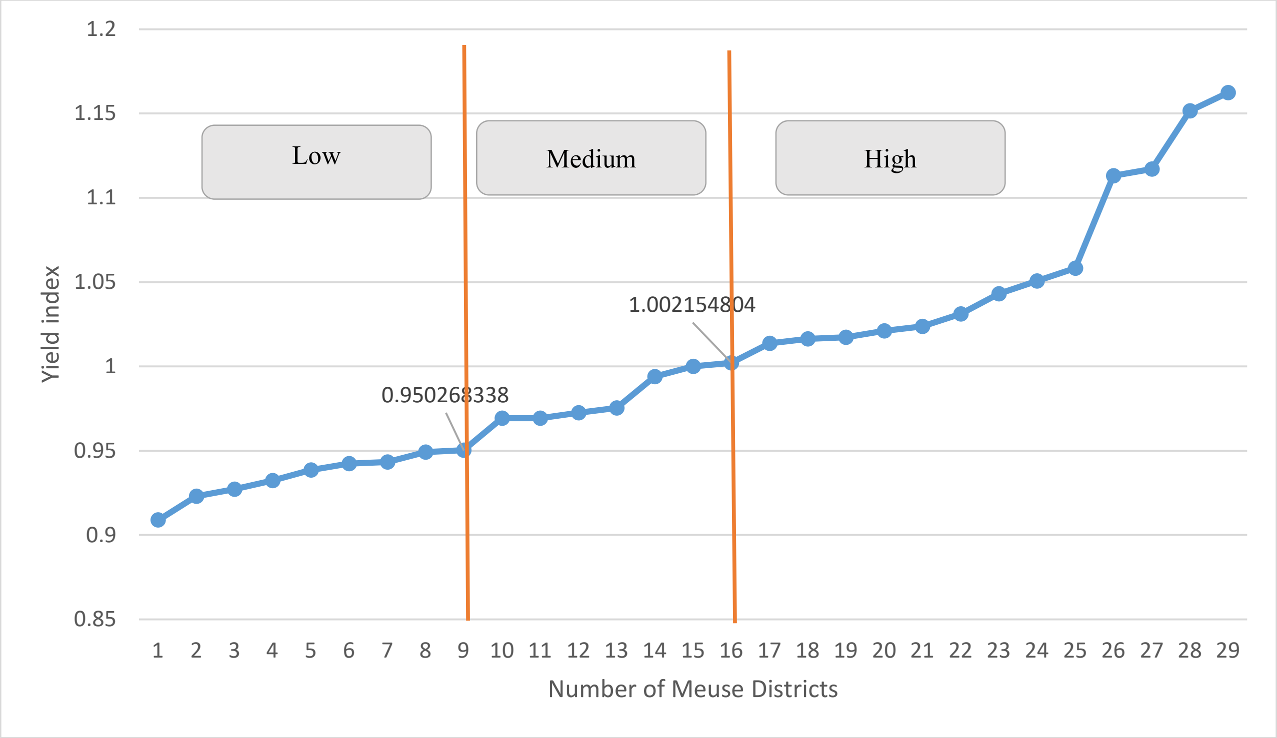


Table 3. Farm groups according to the land quality criterion. *

Groups	Land quality	Nb of farms	Crop land on average in ha	Crop yield in €/ha	Pesticide use intensity in €/ha
1	Low	404	210	961	163
2	Medium	232	176	1077	173
3	High	408	169	1072	162
Total		1044	187	1024	164

*The values for each variable are presented on average over the full period.

The first group, characterized by a low yield index, achieves the expected low level of crop production. This group produces less while using almost the same amount of pesticides per hectare as the third group, which has a high production index. The second group generates slightly more crops than the third but also uses slightly more pesticides per hectare. In terms of farm size, farmers in the first group manage, on average, more hectares of cropland than those in the other two groups.

For the second criterion, we categorized farms based on their subsidy levels, receiving either less or more. Note that our analysis revealed annual variabilities in subsidy amounts across farms, making it challenging to establish a consistent threshold for classification. For more robustness in the farm classification, we used a robust K-means clustering method (Diday and

Brito, 2007). K-means is an algorithm for the automatic classification of elements based on mobile centres to form K clusters of homogeneous elements. It is an unsupervised method of machine learning based on the minimization of within-cluster variation. To apply this method to our second criterion, we first plot the amount of received subsidies as a function of the size of the farm measured by UAA in a scatterplot in Figure 2. Then, we calculate the optimal number of groups that can be obtained from this distribution. To do this, we use the elbow method (reverse elbow), which presents the gain in variability between clusters that can be obtained for each additional group created (the result is presented in Figure 3).

Figure 2. Subsidies vs crop area at the full period

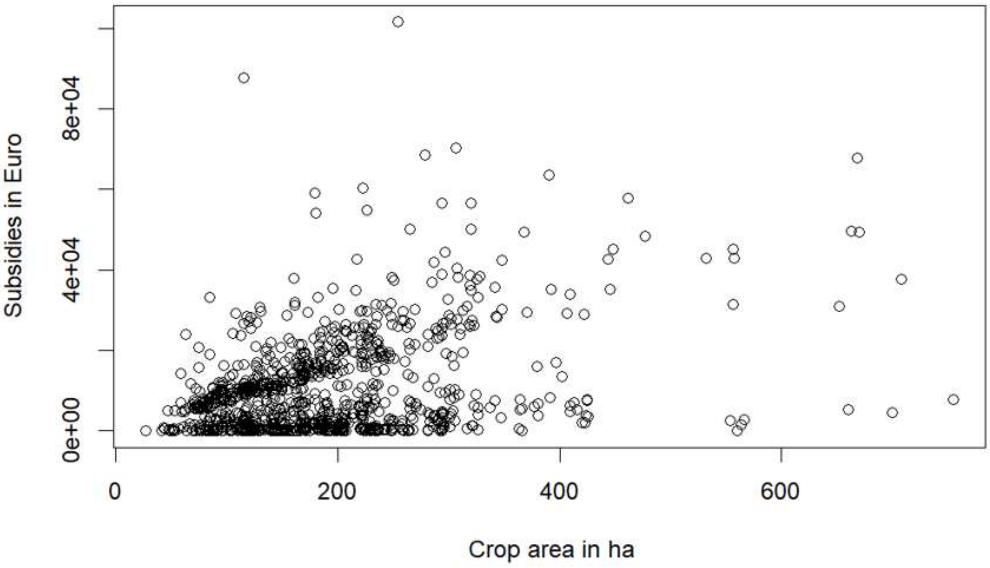
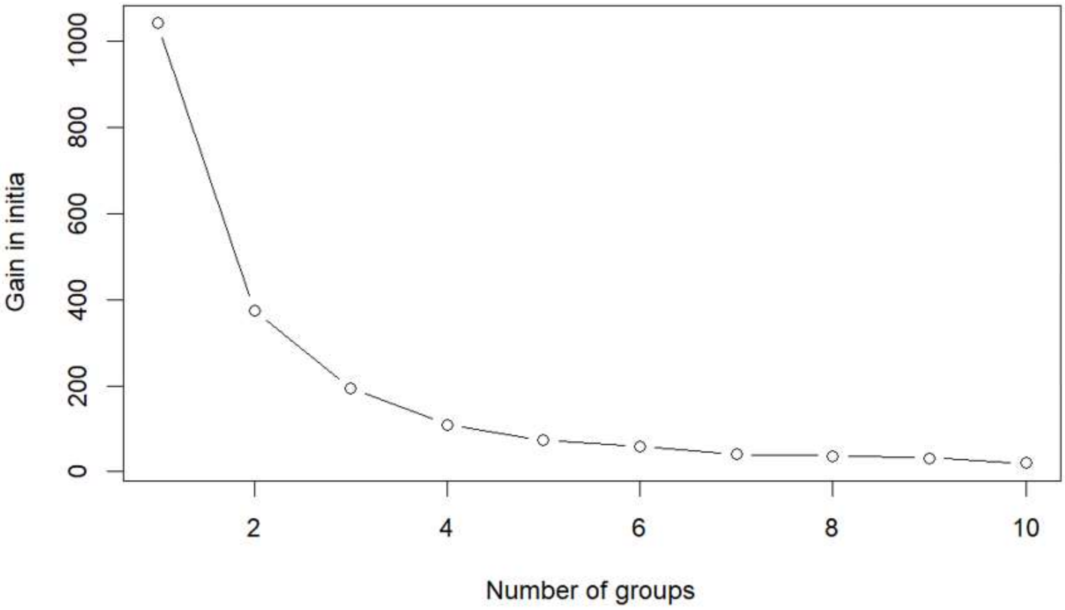


Figure 3. Determining the optimal number of groups



The increase in variability is significant when transitioning from one to two groups. The addition of the third group increases the variability gain, but less pronounced than the second group. Starting from the fourth group, the added gain becomes progressively smaller. Therefore, we conclude that the optimal number of groups to retain is three, plotted in Figure 4. Some of their characteristics are presented in Table 4.

Figure 4. Distribution of subsidies and crop area per cluster.

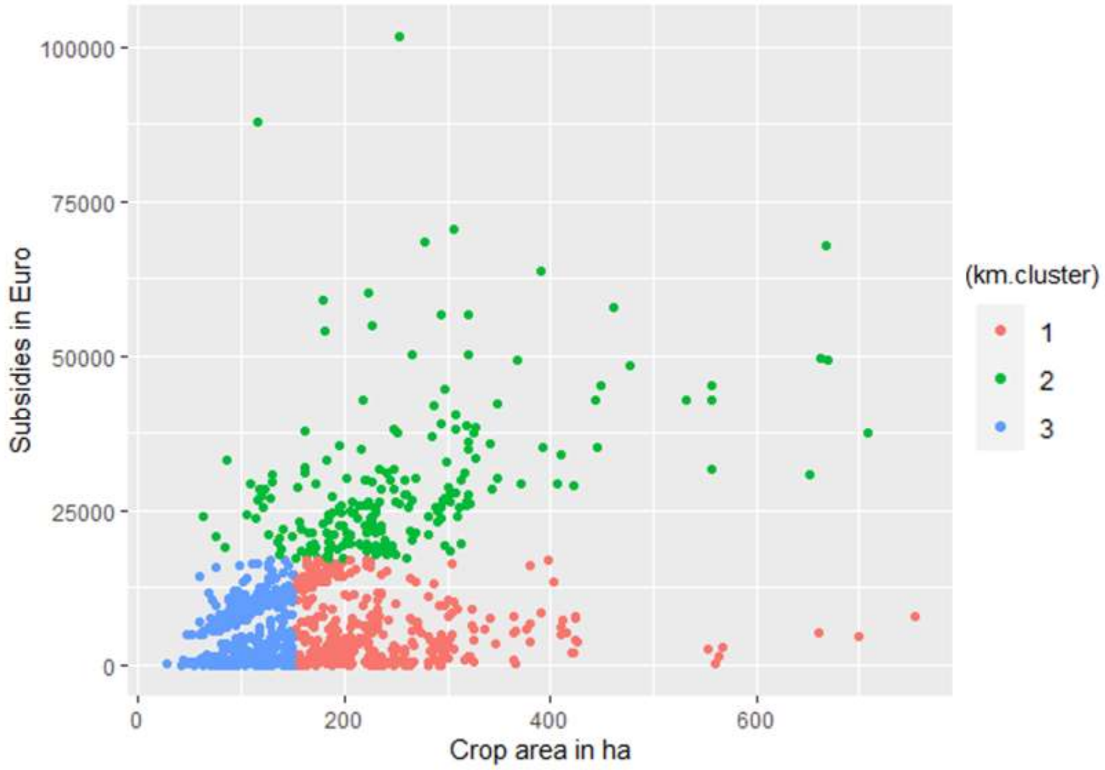


Table 4. Farm groups according to the subsidy level criterion. *

Groups	Level of subsidy	Nb of farms	Subsidy in €	Crop land on average in ha	Crop yield in €/ha	Pesticide use intensity in €/ha
1	Low	420	5,120	228	1,070	168
2	High	220	28,919	252	955	157
3	Low	404	5,326	108	1,012	164
Total		1,044	10,215	187	1,024	164

*The values for each variable are presented on average over the full period.

As seen in this Table, the first and second groups receive fewer subsidies on average and produce relatively more crops, though with slightly higher pesticides use per hectare. Conversely, the second group receives the highest average subsidies but achieves a lower crop production per hectare. Additionally, this latter group manages more land on average than the two other groups.

4. Results

In this section, we first present the potential for implementing each farmland management strategy based on our efficiency measures. Results are presented on the global scale (here, the Meuse department) and over the full period for the 1044 observations. Second, we aggregate inefficiency scores for each strategy for the farm groups by following the two considered criteria. This second step allows us to measure the contribution of each farm group to the implementation of land sharing and land sparing. We consider that the more a farm group contributes to a farmland management strategy, the more appropriate that strategy would be for that group.

4.1. Potential for land-sparing and land-sharing strategies at a global scale

We used the leaner programs (2), (3) and (4) to measure the possibility to implement the land-sparing and land-sharing strategies. Inefficiency scores are presented in Table 5 on average over the period 2006-2016.

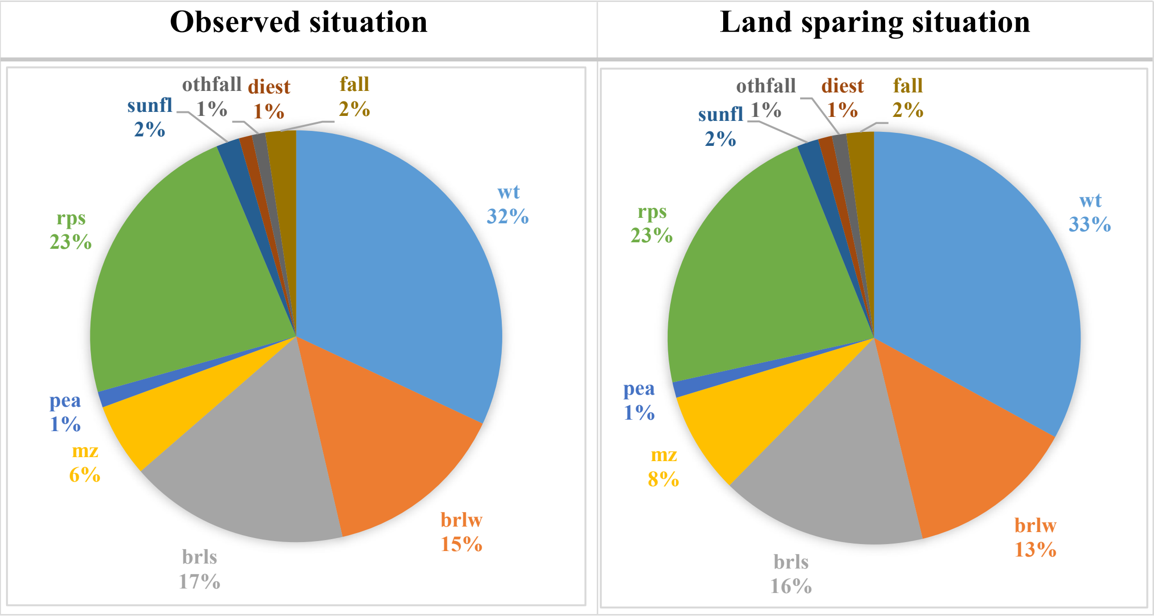
Table 5. Inefficiency scores on average over the ten years for the land-sharing and land-sparing strategies.

	Mean	Standard deviation	Min	Max
Land sparing	0.157076	0.043544	0.076803	0.261699
Land sharing (OP 1)	0.134378	0.026914	0.100752	0.186600
Land sharing (OP 2)	0.078774	0.022135	0.052543	0.135462

The scores indicate that, under the land-sparing strategy, farms in the Meuse department can reduce agricultural land by an average of 15.7% without negatively impacting production levels. This land saving also influences the spatial distribution of crops. As shown in Figure 5, land sparing results in a slight increase in the share of wheat (from 32% to 33%) and maize (from 6% to 8%), but a decrease in winter barley (from 15% to 13%) and spring barley (from 17% to 16%). To understand the preference for wheat and maize in this strategy, we presented the revenues per hectare for each crop in Appendix Figure A. The data show that wheat generates the highest revenue per hectare, followed by maize. This indicates that, to minimize agricultural land in the land-sparing strategy, farmers focus on crops that yield higher revenue.

On the other hand, with the first option of the land sharing strategy, each farm can reduce the intensity use of operational costs on average by 13.4% while maintaining at least the current level of production. And with the second option aiming at simultaneously reducing variable inputs and increasing output on available farmland, the potential for each farm to achieve this double objective is only 7.8% on average.

Figure 5. Impact of the land sparing strategy on the distribution of crops



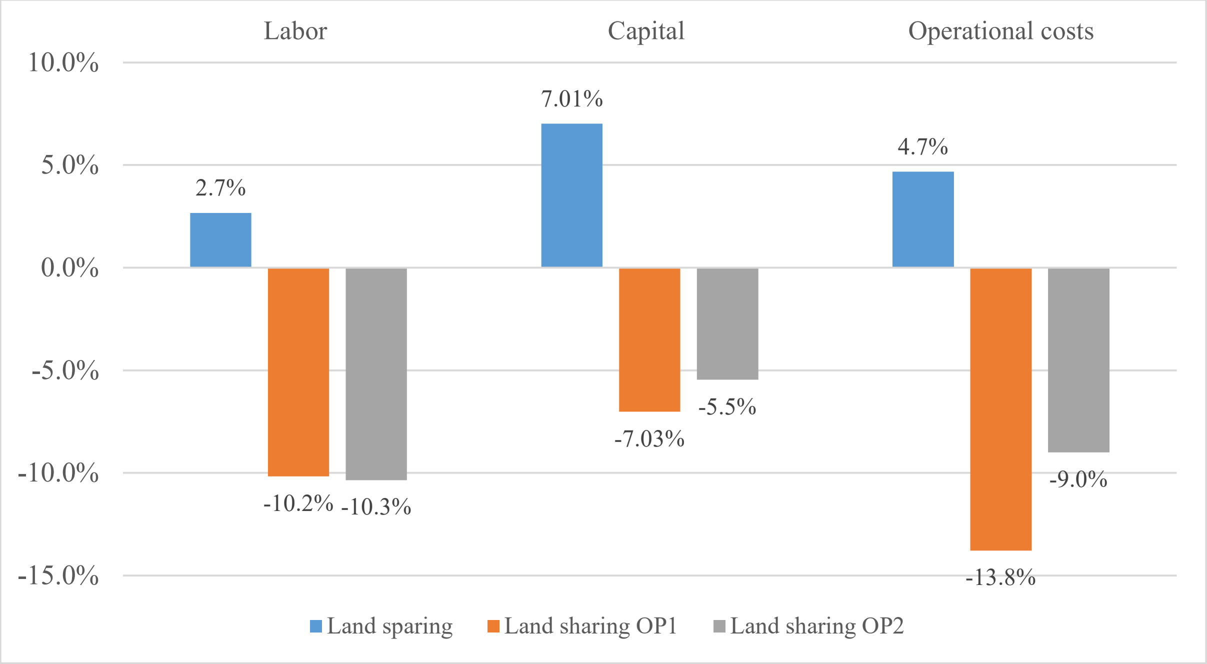
Observed situation

Land sparing situation

In addition to the spatial crop distribution, we assessed the impact of each strategy on the variation of labor, capital, and operational costs per hectare, with findings illustrated in Figure 6. Here, it is evident that land sparing, which allows a saving in land of around 16% for environmental preservation, results in an intensive use of other inputs per hectare. This indicates that, even though farmers can quickly reduce their cultivated areas, certain costs related to equipment, buildings, and family labor may take more time to adjust.

Conversely, the land sharing strategy, in both options, facilitates a reduction in the intensity of all inputs, encompassing capital and labor, while maintaining a steady agricultural land area.

Figure 6. Potential variation in labor, capital, and operational cost intensity under land-sparing and land-sharing strategies



Given these findings, the critical question emerges: which strategy is more conducive to environmental preservation? Should we opt for expanding preserved lands even if it means heightened agricultural intensity, or should we aim to lower agricultural intensity across all farming land while using the maximum area for agriculture? In the following section, we will address an aspect of this issue by identifying the categories of farms for which each of the two strategies would be more appropriate. Here, we assume that the selection of land sparing or land sharing will depend on the specific attributes of the farms capable of implementing it.

4.2. Contribution of farm categories to the land-sharing and land-sparing strategies.

We categorized farms into groups according to the criteria of land quality and the level of subsidy received by each farm.

Considering the land quality criterion in Table 6, the land-sparing strategy results show that farms with the lowest land quality contribute the most to the total reduction of agricultural land (7.1%), compared to farms with the highest land quality, which contribute less (5.8%). This may indicate that high-quality lands are managed more efficiently or that low-quality land is easier to spare for non-agricultural uses. In the land-sharing strategy, however, farms with high-quality land contribute the most to reducing the total use intensity of operational costs in the first option (6%) and simultaneously to reducing total use intensity and expanding outputs in the second option (3.5%).

Table 6. Contribution of farm groups to the two strategies based on the land quality criterion.

	Group 1	Group 2	Group 3	Total
Level of land quality	Low	Medium	High	
Land sparing				
Contribution of farm groups to the reduction of land in %	7.1%	2.9%	5.8%	**15.7%**
Land sharing				
Option 1				
Contribution of farm groups to the reduction of variable inputs in %	4.6%	2.8%	6.0%	**13.4%**
Option 2				
Contribution of farm groups to the variable inputs while increasing the output	2.7%	1.7%	3.5%	**7.9%**

These findings are consistent with those of Martinet and Barraquand (2012) in their analysis of the implementation of the land-sharing and land-sparing strategies for biodiversity conservation on farmland considering the land quality. They concluded that it would be more efficient when it comes to biodiversity conservation to increase agricultural intensification on the best quality land rather than expanding the land-sharing area on lower quality and less productive land. Similarly, Zuluaga et al. (2021) shown that marginal land, that is, with the lowest productivity, must first be allocated to the natural regeneration of forests for ecosystem preservation. Our analysis shows that the higher the land quality of a farm, the less it contributes to the spare of land for other uses than agriculture.

In addition to land quality, we assessed how subsidies influence the feasibility of adopting land sparing and land sharing strategies. Intuitively, one might imagine that the more a farm receives subsidies, the more it contributes to both land sparing and land sharing. Our findings, detailed in Table 7, reveal a contrary trend: farms of the first group, which are typically larger and receive fewer subsidies, contribute the most to the land sparing (8.3%) and land sharing (7.1% in the first option, and 4% in the second option), compared to those in the second group which are on average larger and receive the most subsidies (3.9% in land sparing, 2.7% and 1.6% in the first and second option of land sharing). In other words, these results indicate that for small farms, a low level of subsidies limits their ability to adopt environmentally friendly land management strategies. Conversely, for large farms, the more subsidies they receive, the less they contribute to environmental preservation through agricultural land management. Such a result has been observed in studies analyzing the effects of Common Agricultural Policy subsidies on the technical efficiency of farmers in Europe (Minviel and Latruffe, 2017; Serra et al., 2008). These studies demonstrate that subsidies generally have a negative impact on technical efficiency, as farmers tend to reduce their efforts to improve efficiency or manage risk when they benefit from a guaranteed income.

Table 7. Contribution of farm groups to the two strategies based on the level of subsidy

	Group 1	Group 2	Group 3	
Level of subsidy and farms' size	Low_Large farm	High_Large farm	Low_Small farm	Total
Land sparing				
Contribution of farm groups to the reduction of land in %	8.3%	3.9%	3.4%	**15.7%**
Land sharing				
Option 1				
Contribution of farm groups to the reduction of variable inputs in %	7.1%	2.7%	3.6%	**13.4%**
Option 2				
Contribution of farm groups to the variable inputs while increasing the output	4.0%	1.6%	2.3%	**7.9%**

The contributions of farm groups to land sharing and land sparing suggest that, based on land quality, land sparing would be more suitable for farms with lower land quality, while land sharing would fit better with farms of higher land quality. When considering subsidies, the high contribution of the first group in both strategies indicates that land sparing or land sharing would be more appropriate for large farms that receive fewer subsidies.

5. Conclusion

We analyzed how agricultural production can be reconciled with environmental preservation through agricultural land management strategies. Drawing from rural land management literature, we examined two strategies: land sparing, which spatially separates production from environmental preservation, and land sharing, which integrates the two within the same space. Using an efficiency analysis and an activity model, we measured the potential for each strategy. Directional distance functions assessed the potential reduction in agricultural land at a given production level for land sparing, and the potential reduction in agricultural intensity for land sharing, both at a given production level and with increased production. This analysis was applied to farms in the Meuse department from 2006 to 2016.

The results show that it is possible to reduce the pressure of agriculture on the environment by leaving 16% of agricultural land out of production with the land-sparing strategy or by decreasing the use intensity of operational costs by 13% on all farmlands with the land-sharing strategy at a given level of outputs. Given the aim of simultaneously increasing economic performance while protecting the environment, we see a potential increase in outputs of 8% while decreasing operational costs by the same proportion. These results show what can be given up by choosing one strategy over another at the Meuse department level.

In addition to the overall analysis, we examined farm groups based on land quality and subsidy levels to determine their contributions to land-sharing and land-sparing strategies. This analysis helps identify which strategy would be more appropriate for different farm categories. The results indicate that, based on land quality, land sparing would be more suitable for lower quality farms, while land sharing would be better for higher quality farms. Regarding subsidy levels, both land sparing and land sharing would be more appropriate for large farms that receive fewer subsidies.

The differences in the results corresponding to these two criteria underline the importance of considering farms' characteristics in implementing an agricultural land management strategy for environmental preservation. The land-sparing and land-sharing strategies can then be implemented in conjunction within the same area—as suggested by Fischer et al. (2014); Kremen (2015); and Legras et al. (2018)—by selecting farms for which each strategy is more appropriate based on their characteristics.

Using the available accounting data, we focused on identifying potential means of environmental preservation in the agricultural sector through land-sharing and land-sparing strategies. Due to data limitations, we could not quantify environmental impacts such as biodiversity restoration, water quality preservation, soil erosion risk reduction, and carbon sequestration associated with reduced agricultural intensity or farmland conservation. Future studies should include these environmental analyses to improve our work. Additionally, our study area is relatively homogeneous, as the farms are located within the same small geographic region. This limited variability in climatic and soil conditions does not allow for a clear illustration of different farm categories. For instance, using our land quality criterion, the difference between farms with high-quality and low-quality lands in their contributions to land sharing or land sparing was minimal. A potential improvement to our study would be to expand this analysis on a larger scale, encompassing a greater diversity of farms, when data becomes available.

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Appendix

Figure A. Farm revenue in euro per hectare and crop